

OVERVIEW

- Project start – October, 2018
- Project end – September, 2023 (50% completion)
- Total project funding (to date) – \$525K, DOE share – \$525K, funding for FY20 – \$175K, funding for FY21 – \$175K
- Technical barriers addressed - cost, size and weight, performance, reliability and lifetime

RELEVANCE

- Wide-bandgap devices such as silicon carbide and gallium nitride enable low-cost, lightweight, and power-dense automotive power electronics; however, these technologies are currently limited by power electronics packaging.
- It is critical that the packaging design and materials withstand the high-temperature operational environment introduced by the wide-bandgap devices; bonded interfaces must be reliable under extreme thermal stress conditions.
- The main objective of this project is to evaluate the reliability and study the failure mechanisms of bonded interface materials for high-temperature power electronic applications.

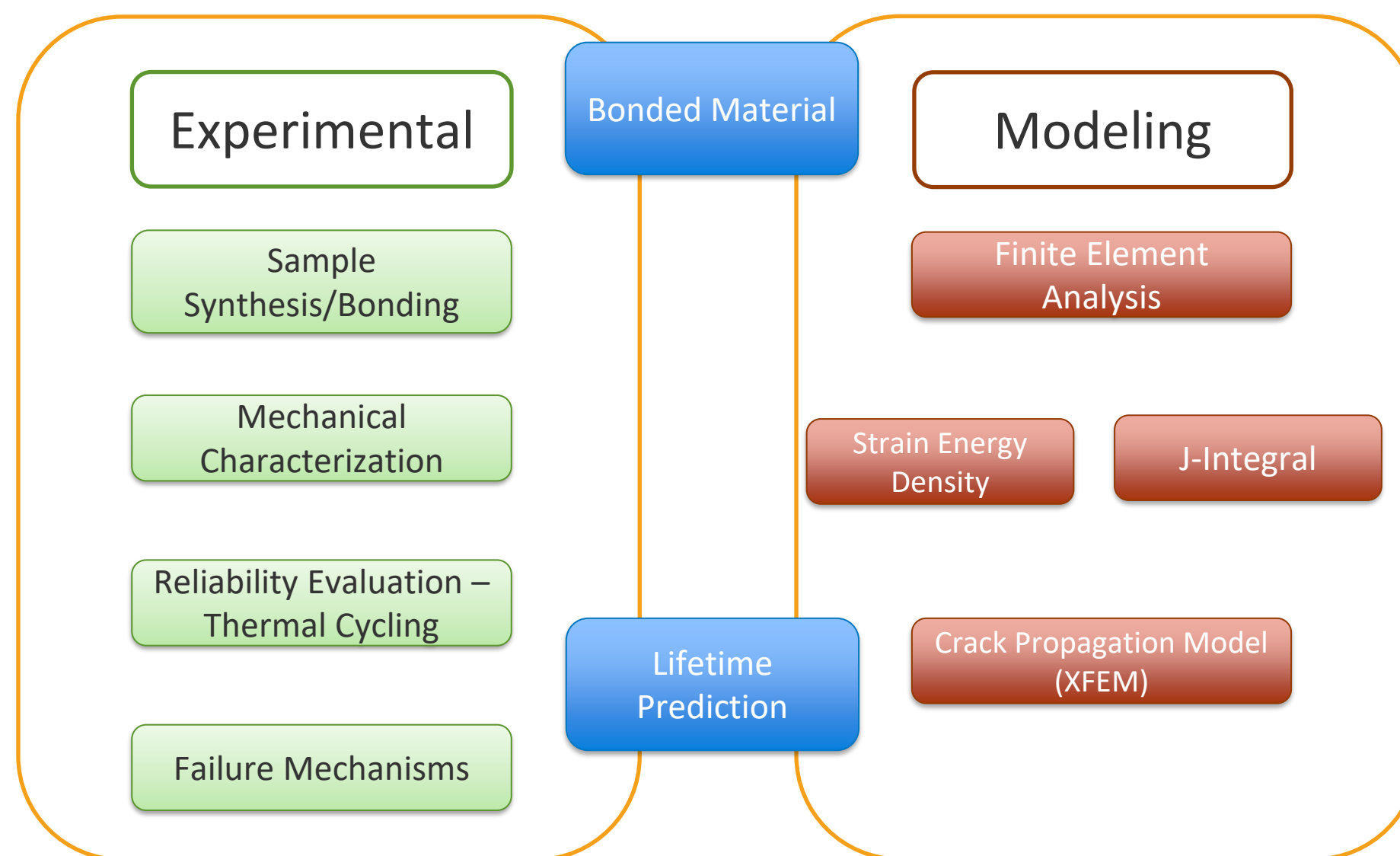
COLLABORATIONS

- Virginia Tech: technical partner on the synthesis of sintered silver bonds
- Georgia Tech: technical partner on the synthesis of Cu-Al bonds
- Oak Ridge National Laboratory & Ames Laboratory: technical guidance and discussion

SUMMARY

- Conducted the reliability evaluation of sintered silver under a thermal cycling profile of -40°C to 200°C ; 95Pb5Sn solder exhibited better thermomechanical performance than sintered silver.
- Formulated a lifetime prediction model of sintered silver by correlating experimental crack growth data with strain energy density outputs from modeling.
- Developed a 2D crack propagation model of sintered silver using the extended finite element method.
- Evaluated the bonding quality of Cu/Al bonds after synthesis; additional refinements are required to reduce the defect fraction.

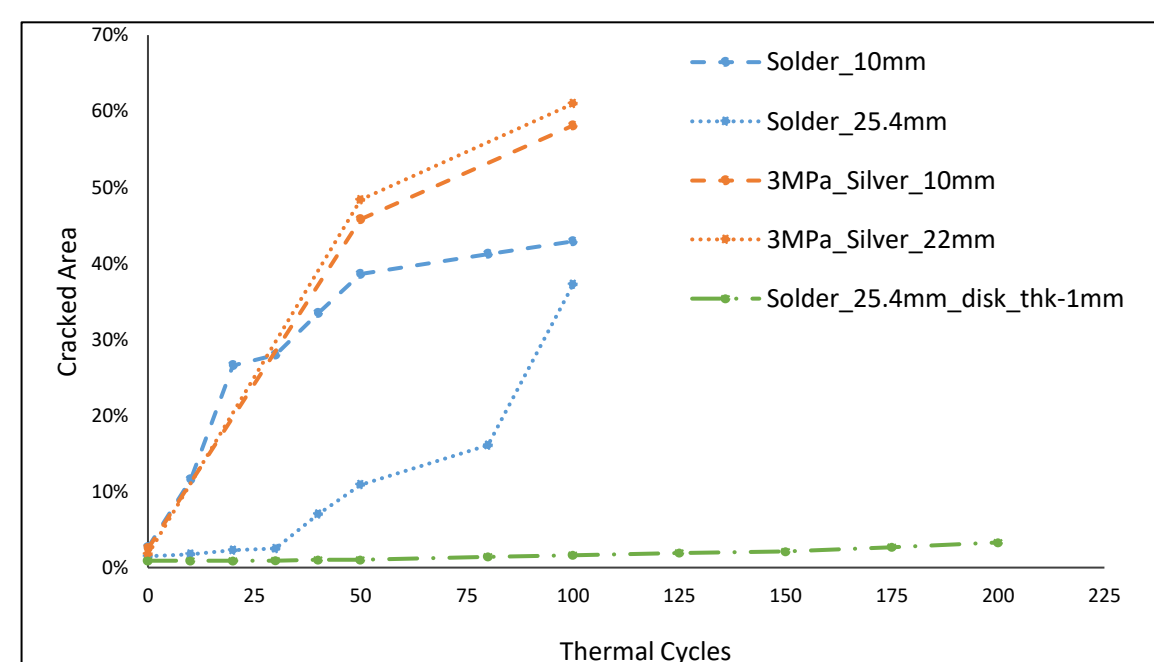
APPROACH



Al: aluminum, AlN: aluminum nitride, AlSiC: aluminum silicon-carbide, DBA – direct bond aluminum, DBC – direct bond copper, Cu: copper, C-SAM: C-mode scanning acoustic microscope, SEM: scanning electron microscope, XFEM: extended finite element method

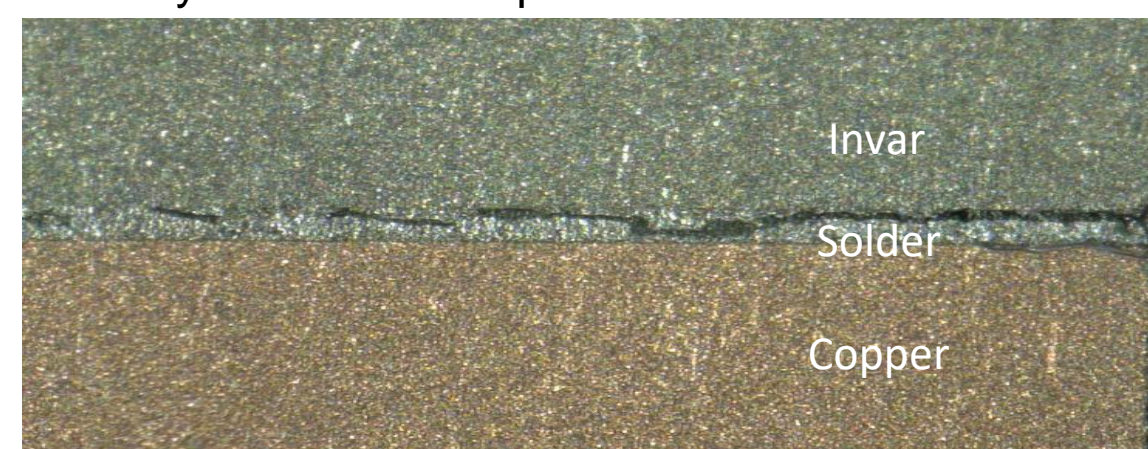
ACCOMPLISHMENTS AND PROGRESS

- Solder (95Pb5Sn) samples exhibited higher reliability than sintered silver under a thermal cycling profile of -40°C to 200°C at both 10-mm- and 25.4-mm-diameter configurations.
- The lower the outer disk thickness, the higher the reliability.
- A correlation was established between the strain energy density results and the experimentally measured crack growth rates of sintered silver to formulate a lifetime prediction model.

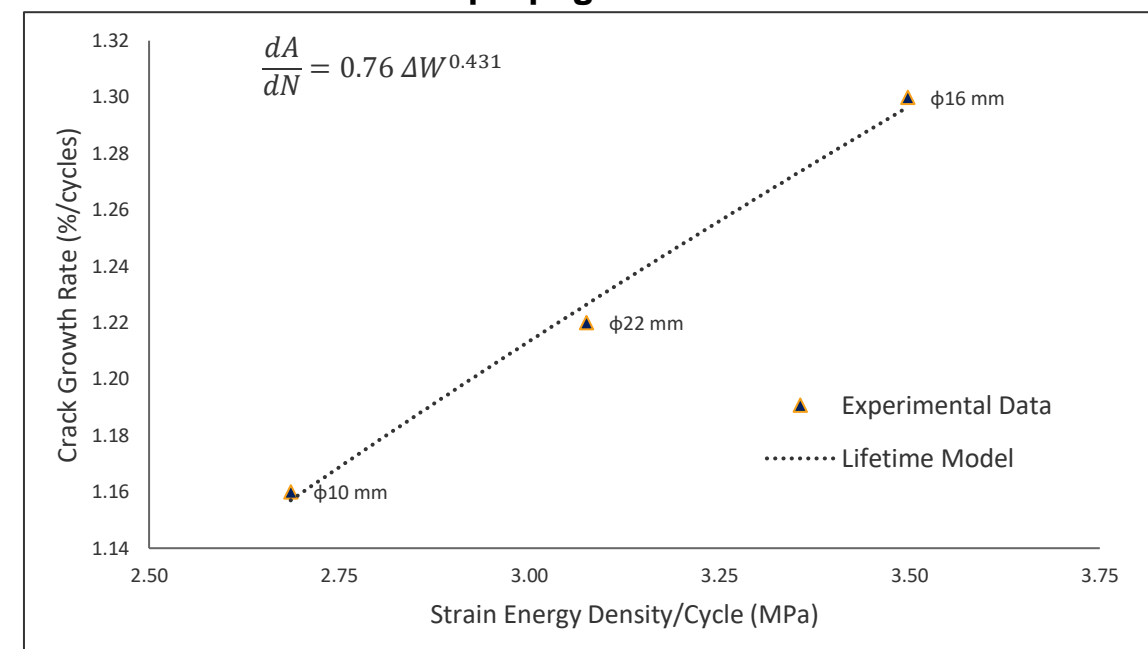


Crack growth comparison of low-pressure-assisted (3 MPa) sintered silver and solder samples under thermal cycling

- The fracture mode of solder was observed to be predominantly adhesive in nature.
- Simulations computed lower values of strain energy density for solder compared to sintered silver.



Crack propagation in solder



Lifetime prediction model of sintered silver

Sample structure

Sintered silver

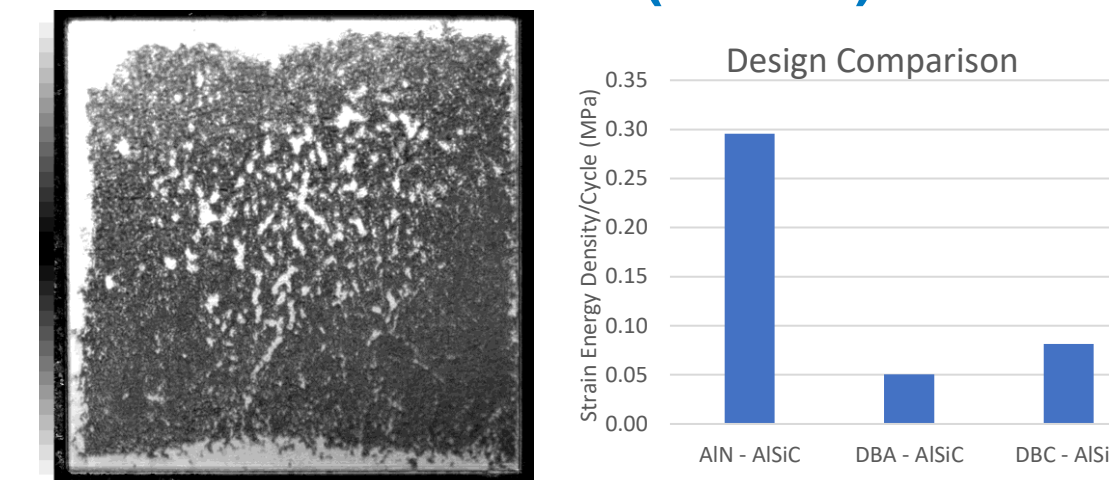
Samples with three different bond diameters were fabricated: 22 mm (left), 16 mm (center), and 10 mm (right)

Cu-Al transient bond

SEM image of Cu-Al bond

- Materials considered in this project are sintered silver and Cu-Al transient liquid-phase alloy.
- These materials are bonded in a sample configuration and subjected to -40°C to 200°C thermal cycling profile.
- C-SAM images of the bond material at periodic cycling intervals would be obtained and analyzed to calculate crack growth rates.
- A lifetime prediction model correlating the crack growth rates and modeling outputs will be developed.

ACCOMPLISHMENTS (contd.)



C-SAM image of a Cu-Al bond between AISiC and AIN (left), strain energy density results of Cu-Al bond under different sample configurations (right)

- Conducted non-linear thermomechanical simulations to study the deformation behavior of Cu-Al bond under thermal cycling.
- Suitable constitutive models for the Cu-Al bond do not exist; used a kinematic hardening model based on Al stress-strain data as an approximation.
- Simulations results indicate that a Cu-Al bond between DBA and AISiC is more reliable than AIN and AISiC however, this trend may change with a more appropriate constitutive model; also, it is experimentally challenging to create a Cu-Al bond with DBA.

CHALLENGES AND BARRIERS

- Correlation between simulations and experimental results is hard to establish due to the macroscopic nature of modeling and microstructural causes of failure mechanisms in bonded materials.
- While current formulations of sintered silver may work for small-area attach (die-attach), novel material compositions and microstructures need to be identified for large-area attach layers with sufficient reliability.
- Synthesis profile and parameters of Cu-Al bond need to be optimized to reduce the initial void fraction to acceptable levels (<5%).

FUTURE WORK

- Conduct accelerated thermal cycling of Cu/Al bond samples under different temperature profiles: -40°C to 200°C and -40°C to 175°C .
- Expand the microstructural crack propagation model to include physics at lower length and time scales and establish microstructure-property relationships to accelerate novel high-temperature material development.
- Identify new material compositions for reliable operation at high temperature through experimental and data-driven modeling approaches.

Any proposed future work is subject to change based on funding levels.